ACTIVITY 6

Quantifying Scientific Uncertainty

COMPUTER SIMULATION

Motorbike taxis, also called boda bodas, are a common source of transportation in Uganda. Researchers have found a way to attach air monitoring sensors to them in order to gather air quality data from around the city.

6: QUANTIFYING SCIENTIFIC UNCERTAINTY

GUIDING QUESTION

How can you reduce random errors and systematic errors in data?

INTRODUCTION

How can you reduce scientific uncertainty when investigating air quality? In 2022, a team of Ugandan researchers led by Engineer Bainomugisha developed an air monitoring technology that predicts pollution patterns. The technology was designed for local conditions in the country's capital, Kampala. Because it is solar powered, it can be installed in areas not connected to the energy grid. Air monitoring sensors are placed on top of buildings and on motorbike taxis. The motorbike taxis are driven around the city and provide air quality data from multiple areas. This reduces the likelihood of systematic error in the air quality readings. The researchers then use artificial intelligence (AI) software to review real-time data and predict pollution levels. The resulting information is used to develop clean-air policies and local health policies. In this activity, you will examine how random errors and systematic errors can affect data and ways in which these errors can be addressed.

Professor Engineer Bainomugisha and student Priscilla Adong install air monitoring technology in Kampala, Uganda in 2019.

> If you need to review the concepts of reliability, accuracy, precision, and validation, you will find a Science Review at the end of this activity.

CONCEPTUAL TOOLS

PROBABILISTIC REASONING

SYSTEMATIC & RANDOM ERROR

SIGNAL & NOISE

MATERIALS LIST

FOR EACH PAIR OF STUDENTS

- COMPUTER WITH INTERNET ACCESS

FOR EACH STUDENT

- STUDENT SHEET 6.1 "Testing Air Quality Sensors"

PROCEDURE

PART A: TESTING A PHOTOMETER

1 Read the following fictional scenario.

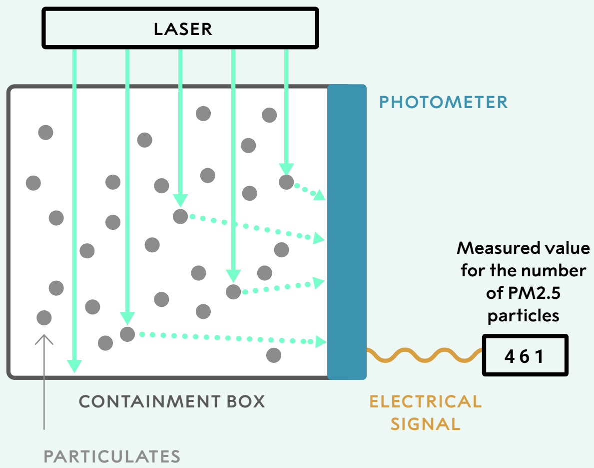
NEW STARTUP WANTS TO CLEAR THE AIR

A new startup company called Blase-Air has developed technology to improve air quality sensors. The technology is a new version of a light sensor called a photometer that is used inside air quality sensors, shown in Figure 6.1. Although it is still being tested, company engineers claim that the new photometer is more accurate than the old one.

Based on the test results, Blase-Air will decide whether they should use the new photometer in place of the older one in their air quality sensors.

The sensor works by flashing a laser into an air sample. The rays of the laser reflect off of the particulates and are collected by a photometer. The photometer converts the scattered laser signals into electrical pulses that are then used to calculate the number of PM2.5 particulates in the air sample. The device takes this measurement multiple times on a single air sample and provides an average of the measurements.

FIGURE 6.1
Air Quality Sensor



2 You and your partner will play the role of the team that is testing the new air quality sensor for the Blase-Air company. Follow your teacher's instructions for accessing the Scientific Uncertainty Simulation. This computer simulation contains the following three experiments:

EXPERIMENT 1 Investigate how well the original photometer (Photometer 1) measures PM2.5 levels.

EXPERIMENT 2 Investigate whether an appliance running next to Photometer 1 affects the data from Photometer 1 and, if so, how.

EXPERIMENT 3 Compare data from Photometer 1 to the new photometer (Photometer 2).

3 Conduct 5 trials of Experiment 1. Observe how the graphs change as you conduct each trial.

4 Select the SHOW TRUE VALUE and SHOW ERROR BARS buttons. In Figure 6.2, the true value refers to the actual number of PM2.5 particulates present in the air sample being tested. Error bars are a visual representation of the amount of uncertainty in a measurement, presented as a ± (plus or minus) range of numbers that fall above and below the average. In this simulation, the error bars were calculated using a 95% confidence interval. This means that if the experiment was repeated 100 times, the true value would be within the range of the error bars 95 times.

In Table 1 on Student Sheet 6.1, "Testing Air Quality Sensors," record the average, the error bar range, and the true value from your 5 trials.

FIGURE 6.2
Sample Graphs from Scientific Uncertainty Simulation

5 Graph 1, “Average of All Trials, Photometer 1,” plots all the individual data points vertically, while Graph 2, “Current Average, Photometer 1,” shows how the average of the data changes with more trials. Compare the data in your Graphs 1 and 2 from the simulation by discussing the following with your partner:

- your observations of each graph.
- what Graphs 1 and 2 might look like if there were a) no error, b) random error, and c) systematic error.

6 Conduct more trials until the error bar is ± 3. In the bottom row of Table 1 on the student sheet, record the number of trials it takes to get to an error bar range of ± 3, along with the average and the true value.

HINT: If you hover over the average line, you can see the average for any trial in the past. When you have SHOW ERROR BARS toggled on, you can see how the error bar range changes as you add more data points.

7 Use the results of Experiment 1 to discuss the following with your partner:

- how the number of trials affected the true value, the average, and the error bars.
- whether conducting more trials makes your average more accurate (closer to the true value) and why or why not.

8 Proceed to Experiment 2. Repeat Steps 3–6 for Experiment 2 and record your data in Table 2 on the student sheet.

9 Select the SHOW DATA FROM EXPERIMENT 1 button to see the data from Experiment 1 (when there was no appliance on). With your partner, determine whether the electric field of the appliance affected the measurements by:

a comparing the size of the error bars for Experiment 1 (no appliance on) and Experiment 2 (appliance on).

b comparing the averages for both Experiment 1 (no appliance on) and Experiment 2 (appliance on) to the true value.

10 Discuss with your partner what type(s) of error (systematic, random, or both) are likely to be occurring in Experiments 1 and 2. Be sure to explain your reasoning.

PART B: COMPARING TWO PHOTOMETERS

11 Proceed to Experiment 3 to investigate how well the air quality sensor functions with the old photometer (Photometer 1) compared with the new model (Photometer 2).

- a Repeat Steps 3, 4, and 6 for Experiment 3 and record your data in Table 3 on the student sheet. Make sure to record data for both Photometer 1 and Photometer 2.

  HINT: It may be helpful to have one partner watch and record data for Photometer 1 while the other watches and records data for Photometer 2.

- b Examine both graph types by selecting the CHANGE GRAPH TYPE button at the top of the screen to see how the average changed over time.

12 Use the data from Experiment 3 to determine which photometer:

- a has an average measurement that is most accurate (closest to the true value).
- b had less scientific uncertainty in the data.

  HINT: For each photometer, consider the size of the error bars as well as how spread out the data points are.

- c required fewer trials for the average to reach error bars within ± 3 of the true value.

13 As a class, evaluate the claim that the new Photometer 2 is more accurate than the old Photometer 1. Decide which photometer Blase-Air should use in their air quality sensor design.

BUILD UNDERSTANDING

① Consider how the data changed during the experiments in the computer simulation. How does conducting more trials affect how close the average is to the true value when there is:

- a random error?
- b systematic error?

② Error bars play an important role in communicating about scientific uncertainty in data. Describe how the size of the error bars can affect scientific uncertainty in a conclusion. Include an example from the computer simulation in your response.

③ Think back to the concepts of signal and noise from Activity 2: Signal and Noise. Explain how the presentation of data in the computer simulation helped differentiate the signal from the noise.

4 Figure 6.3 shows air quality data from five sensors in the same location. Each line represents a different sensor.

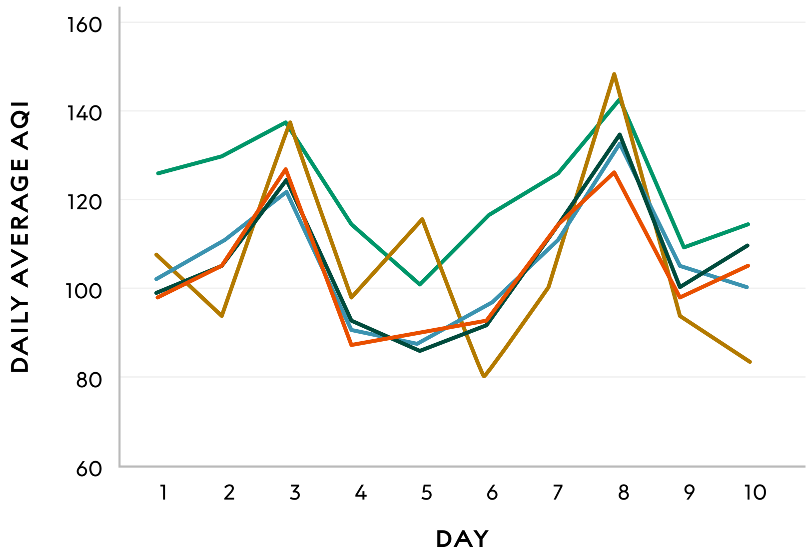


FIGURE 6.3
Data from Five Air Quality Index (AQI) Sensors

- Sensor 1
- Sensor 2
- Sensor 3
- Sensor 4
- Sensor 5

a Which sensor is most likely to have a systematic error? Explain your reasoning.

b Which sensor appears to have random error? Explain your reasoning.

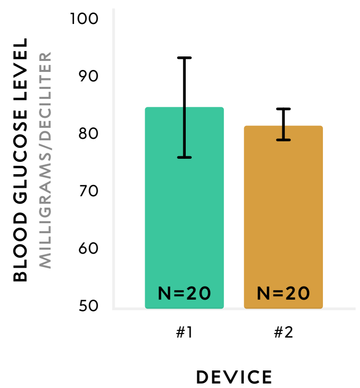
CONNECTIONS TO EVERYDAY LIFE

5 Glucose is a type of sugar that your body uses for energy. Imagine that you read about a study comparing two different glucose meters for measuring glucose levels in the blood of patients with diabetes. Each glucose meter measured the same blood sample 20 times (N = 20). Figure 6.4 shows glucose level averages, shown with error bars, that were calculated for each glucose meter.

a What can you determine about the uncertainty of the data collected by each device?

b Can you be sure which device is measuring blood glucose levels closer to the true value? Explain why or why not.

FIGURE 6.4
Comparing Glucose Meters



KEY SCIENTIFIC TERM

error bars

SCIENCE REVIEW

Reliability, Accuracy, Precision, and Validation

Scientific explanations depend on relevant, accurate, and reliable data. Data is considered *reliable* if it is able to be reproduced consistently. For example, if an air sensor near you measures the AQI three different times in immediate succession and all three times it measures an AQI score of 32, then the sensor is very reliable. If a sensor measured an air sample three times and read 32, 59, and 67, then the sensor is not reliable. *Accuracy* is the closeness of a measured value to a standard or true value. For example, if your crowdsourced air sensor at home measures the same AQI as a nearby government air monitoring station that is higher quality and carefully calibrated, then you can say that your at-home air sensor is accurate. *Precision* is how close measurements of the same item are to each other. The farther the points are from each other, the lower the precision. For example, you placed two air quality sensors next to each other in your backyard and checked the AQI readings three times in an hour. Sensor 1 measured 32, 35, and 26. Sensor 2 measured 20, 45, and 35. Sensor 1 has a higher precision than Sensor 2.

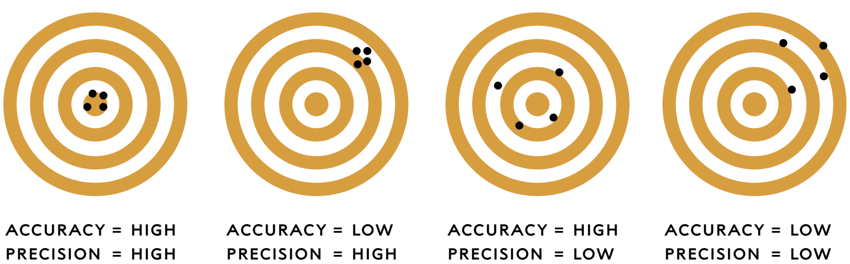


FIGURE 6.5
Accuracy vs. Precision

Validation is a process of determining the accuracy of a measurement. For example, when a scientist wants to determine the accuracy of her air sensor equipment, she can validate it in the lab by observing how close the measurement is to an air sample with a known concentration of air pollutants.